NOAA Technical Memorandum NMFS

OCTOBER 2010

SPAWNING BIOMASS OF PACIFIC SARDINE (*Sardinops sagax*) off the U.S. in 2010

Nancy C. H. Lo
Beverly.J. Macewicz
and
David A. Griffith

NOAA-TM-NMFS-SWFSC-463

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and maybe referenced in the formal scientific and technical literature.

NOAA Technical Memorandum NMFS
This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

OCTOBER 2010

SPAWNING BIOMASS OF PACIFIC SARDINE (*Sardinops sagax*) off the U.S. in 2010

Nancy C. H Lo, Beverly J. Macewicz, and David A. Griffith

National Oceanic & Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037

Nancy.Lo@noaa.gov

NOAA-TM-NMFS-SWFSC-463

U.S. DEPARTMENT OF COMMERCE
Gary F. Locke, Secretary
National Oceanic and Atmospheric Administration
Jane Lubchenco, Undersecretary for Oceans and Atmosphere
National Marine Fisheries Service
Eric C. Schwaab, Assistant Administrator for Fisheries

This page intentionally left blank.

SUMMARY

The spawning biomass of the Pacific sardine (*Sardinops sagax*) in April 2010 was estimated using the daily egg production method (DEPM) calculated by two methods: 1) the traditional method where the egg production (P_0) was a weighted mean while each adult parameter was an unstratified estimate, and 2) a stratified procedure where the estimate of total spawning biomass is the sum of the estimated spawning biomass in each of two regions representing high and low spawning activity. Thus the two estimates of the spawning biomass were 100,578 mt (CV = 0.38) and 96,622 mt (CV = 0.38) for the entire survey area of 477,092 km^2 off the west coast of North America from San Diego, U.S.A. to Cape Flattery, Washington (30.6° – 48.07°N), primarily for the area south of 38°N. The daily egg production estimate (P_0, a weighted average with area as the weight) was 0.21/.05m^2 (CV = 0.32). No eggs were collected in the area north of CalCOFI line 56.7, and sardines were caught at only one station north of CalCOFI line 60 (at 38.2°N). The standard DEPM survey area off California, from San Diego to San Francisco (CalCOFI lines 95 to 60), in 2010 was 271,773 km^2 and the egg production estimate was 0.36/0.05m^2 (CV = 0.40). The two estimates of spawning biomass of the Pacific sardine (*Sardinops sagax*) in April 2010 for the standard DEPM area were 108,280 mt (CV = 0.46) and 105,220 mt (CV = 0.40). The point estimates of total spawning biomass for the standard DEPM survey area were greater than those for the whole survey area using either the traditional method or the stratified procedure. However, the differences of spawning biomass between the standard DEPM survey area and the entire survey area were not statistically significant due to the high CV values. In the standard DEPM area, the estimates of female spawning biomass calculated by the two methods were 62,131 mt (CV = 0.46) and 58,447 mt (CV = 0.42).

The estimated of daily specific fecundity was 18.07 (number of eggs/population weight (g)/day) using the following estimates of reproductive parameters from 313 mature female Pacific sardines collected from 17 positive trawls: *F*, mean batch fecundity, 39304 eggs/batch (CV = 0.03); *S*, fraction spawning per day, 0.104 females spawning per day (CV = 0.22); W_f, mean female fish weight, 129.5 g (CV = 0.02); and *R*, sex ratio of females by weight, 0.574 (CV = 0.07). Since 2005, trawling has been conducted randomly or at CalCOFI stations, which resulted in sampling adult sardines in both high (Region 1) and low (Region 2) sardine egg-density areas. In 2010, more positive tows were observed in Region 2 than Region 1.

The estimates of spawning biomass of the Pacific sardine off California in 1994 – 2010 based on the traditional method are: 127,000 mt, 80,000 mt, 83,000 mt, 410,000 mt, 314,000 mt, 282,000 mt, 1.06 million mt, 791,000 mt, 206,000 mt, 485,000 mt, 300,000 mt, 600,000 mt, 837,000 mt, 392,00 mt, 117,000 mt, 185,000 and 108,000mt (for the standard DEPM area), respectively. These estimates of spawning biomass indicate that there has been considerable fluctuation during this time (the peaks occurred in 2000 and 2006) and that biomass has declined in the recent three years. The time series of spawning biomass was one of the fishery-independent inputs to the annual stock assessment of the Pacific sardine from 1985 – 2008. Since 2009, the time series of spawning biomass was replaced by female spawning biomass for years when sufficient trawl samples were available and the total egg production for other years as inputs to the stock assessment of Pacific sardine.

This page intentionally left blank.

INTRODUCTION

The spawning biomass of the Pacific sardine (*Sardinops sagax*) was estimated using the daily egg production method (DEPM: Lasker 1985) in 1986 (Scannel et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), and 1996 (Barnes et al. 1997). The DEPM estimates spawning biomass by 1) calculating the daily egg production from ichthyoplankton survey data, 2) estimating the reproductive parameters of females from adult fish samples, and 3) calculating the biomass of spawning adults. Before 1996, sardine egg production was estimated from CalVET plankton net samples. Adult fish were sampled in various ways prior to 1996 to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average female fish weight (Wolf 1988a, 1988b; Scannell et al. 1996; Macewicz et al. 1996; Lo et al. 1996).

Since 1996, in addition to CalVET and Bongo nets, the Continuous Underway Fish Egg Sampler (CUFES; Checkley, et al. 1997) has been used as a routine sampler for fish eggs, and data on sardine eggs collected with CUFES have been incorporated in various ways into the estimation procedures of the daily egg production. In the 1997 sardine egg survey (Hill et al. 1998, Lo et al. 2001), CUFES was used to allocate CalVET tows in an adaptive sampling plan. From 1998 to 2000, data on sardine eggs collected with both CalVET and CUFES during each April California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise were used to estimate daily egg production (Hill et al. 1999). Use of the full data sets from both samplers in the DEPM can be time consuming. Furthermore, the CUFES samples are exclusively from 3 m depth and it is not clear whether sardine egg stages from CUFES samples are representative of the entire vertical distribution of stages. Use of the CUFES data also requires an estimated conversion factor from eggs/min to eggs/0.05m^2. Starting with the 1999 April CalCOFI survey, an adaptive allocation survey design similar to the 1997 survey was implemented. In this design, CalVET tows are added in areas where they were not preassigned if sardine egg densities in CUFES collections were high.

Since 2001, a cost-effective alternative has been adopted to calculate the DEPM index that reduces effort in calculation and egg staging of the CUFES collections. This revised DEPM index only uses CalVET samples of eggs and yolk-sac larvae and Bongo samples of yolk-sac larvae, all from the high density area (Region 1), to provide an estimate of P_0, the variance of which may be large due to small sample size (fewer than 100 plankton tows). Adult samples were collected sporadically in 1997, 2001, and 2002 (Lo et al. 2005).

Starting in 2004, full-scale surveys have been conducted for collection of Pacific sardine eggs, larvae, and adults to better estimate the spawning biomass in the area off California between San Diego and San Francisco (Lo and Macewicz 2004; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2006 a,b; Lo et al. 2007a,b, 2008, Lo et al. 2009). In 2004 the adult samples were taken primarily in the high density area, but beginning in 2005 adult Pacific sardine samples for reproductive output were taken in both high and low sardine egg density areas. The ichthyoplankton samples taken during regular April CalCOFI cruises were also included in the spawning biomass computation. During 2006 and 2008, the survey area was extended north to the US-Canadian border, and spawning biomass was computed for both the whole survey area and the standard DEPM survey area, i.e. from San Diego to San Francisco.

For 2010, although the majority of the eggs and adults were observed in the area south of CalCOFI line 60, the spawning biomass was estimated for the entire survey area in addition to this sub-area, i.e. the DEPM area.

Since 2009, in addition to the estimates of spawning biomass based on the past procedure where P_0 was weighted by the size (km^2) of each region and the adult parameters were estimated from all trawl samples in the entire survey area, an alternative estimator based on stratified sampling for each parameter was also included (Hill et al. 2009) for years when adequate adult samples were available (1986, 1987, 1994, 2004, 2005, 2007 – 2010). As such, the original time series of spawning biomass may not be comparable due to slightly different estimation procedures and the refined survey designs over time. This alternative method was also used to estimate the female spawning biomass that is now used as a data time series for stock assessment computations. Here, we report the time series of spawning biomass, female spawning biomass, and total egg production based on both the traditional method and the stratified estimates.

MATERIALS AND METHODS

Data

The spring 2010 California Current Ecosystem (CCE) survey was conducted aboard one NOAA research vessel and a chartered fishing vessel. The NOAA ship *Miller Freeman* (April 2 – 22) covered the area off California from San Diego to Monterey Bay (CalCOFI lines 95 to 66.7) and the F/V *Frosti* (March 28 – April 28) covered the area from just south of Cape Flattery, Washington to just south of Monterey Bay, California (48.07°N to 34.88°N, i.e. CalCOFI line 70). During the CCE surveys, CalVET tows, Bongo tows, CUFES and trawls were conducted aboard both vessels. After the CCE survey, the routine spring CalCOFI survey was carried out aboard the NOAA ship *Miller Freeman* from April 26 – May 17 to cover six lines from 93.3 to 76.6 and only CalVET and Bongo tows were taken. Only data from CCE survey were included in estimation of spawning biomass of Pacific sardines.

In addition to sardine eggs and yolk-sac larvae collected with the CalVET net, yolk-sac larvae collected with the Bongo net have been included to model the sardine embryonic mortality curve since 2000. Beginning in 2001 (Lo 2001), CUFES data from the ichthyoplankton surveys have been used only to map the spatial distribution of the sardine spawning population with the survey area post-stratified into high-density (Region 1) and low-density (Region 2) areas according to the sardine egg density from CUFES collections. Staged eggs from CalVET tows and yolk-sac larvae from CalVET and Bongo tows in the high-density area have been used to model embryonic mortality in the high density area and later converted to the daily egg production, P_0, for the whole survey area.

During the 2010 CCE survey, twenty six distinct transects were occupied by the research vessels. The *Miller Freeman* occupied 9 out of 12 planned lines and the *Frosti* occupied 17 out of 23 planned lines. CalCOFI line 66.7 was occupied once by the *Miller Freeman* using the standard sampling protocol of trawling and ichthyoplankton tows and then again simultaneously by both vessels to take comparative CUFES samples. During the comparison, the *Miller*

Freeman followed three minutes behind the *Frosti* on the same cruise track and CUFES sampling was adjusted to sample the same water mass. This comparitive data have yet to be analyzed. The distance between transect lines ranged from 20 to 60 nm. Due to weather condition, some lines were not fully occupied by the *Frosti* and, due to mechanical delays, the *Miller Freeman* was not able to occupy all proposed stations. For the CCE survey, CalVET tows were taken at 4-nm intervals on each line after the egg density from each of two consecutive CUFES samples exceeded 1 egg/min, and CalVET tows were stopped after the egg density from each of two consecutive CUFES samples was less than 1 egg/min. The threshold of 1 egg/min was reduced from the number used in years prior to 2002 (2 eggs/min) to increase the area identified as the high-density area and, subsequently, to increase the number of CalVET samples. One egg/min is equivalent to two to thirteen eggs/CalVET tow, depending on the degree of water mixing. This adaptive allocation sampling was similar to that used in the 1997 survey (Lo et al. 2001). Because the threshold changed in 2002, caution should be taken when comparing the size of the area of Region 1.

The entire survey area was 477,092 km^2 in 2010. However, only the 271,773 km^2 south of CalCOFI line 60.0 (37.94°N latitude) was used to estimate the initial P_0, because no eggs and only one positive trawl were collected north of 38°N. This southern area was post-stratified into two regions: Region 1 (high sardine egg density) and Region 2 (low egg density). Region 1 encompassed the area where the egg density in CUFES collections was at least 1 egg per minute (Figure 1). The sizes of Region 1 and the entire survey area were calculated using the formula for a trapezoid area based on the distance between CalCOFI lines and the distance between CalCOFI stations. Region 1 was 27,462 km^2 (10.1% of the area south of line 60.0) and Region 2 was 244,311 km^2. Although the area south of CalCOFI line 60.0 is slightly smaller than the area surveyed in 2009 because the most offshore station was CalCOFI station 90, it is the standard DEPM area surveyed off California in 2010. Over the years, although the standard DEPM survey area has varied in size, it has been approximately between CalCOFI line 60 (near San Francisco) and line 95 (near San Diego).

A total of 828 CUFES samples were collected from the *Frosti* (495) and *Miller Freeman* (333) cruises over the whole survey area. For the DEPM area (CalCOFI line 60 to 95), 568 CUFES samples were taken by the *Miller Freeman* (333) and *Frosti* (235). CUFES sampling intervals ranged from 2 to 60 minutes with a mean of 37.53 minutes and median of 31 minutes. The total number of CalVET tows was 164 for the entire survey area, with 129 in the standard DEPM survey area. A total of 46 CalVET samples caught at least one egg (Table 1). Egg densities from each CalVET sample and from the CUFES samples taken within an hour before and after the CalVET tow were paired and used to derive a conversion factor (E) from eggs/min of CUFES sample to CalVET catch (eggs/tow). We used a regression estimator to compute the ratio of mean eggs/min from CUFES to mean eggs/tow from CalVET: $E = \mu_y / \mu_x$ where y is eggs/min and x is eggs/tow.

For adult samples, the survey plan was to use the *Miller Freeman* and the *Frosti* to conduct 3 – 5 trawls a night either near regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections. In addition, it was planned to conduct some directed trawls in the daytime on acoustic targets to verify potential sardine schools. At night a Nordic 264 rope trawl with 3.0 m^2 foam core doors was towed for 30 minutes at the surface (0 – 11 meters). The trawl was modified for surface trawling with Polyform floats attached to the head rope and trawl wings. The trawl was modified with a marine mammal extruder device placed midsection just forward of the codend. In the daytime, the trawl was used without the Polyform floats and towed at depths of 14 to 174 meters. For the whole CCE survey trawling occurred from March 30 to April 27, 2010 and 19 of the 90 trawls conducted at night were positive for Pacific sardines but none of the 8 trawls conducted during daylight hours contained sardines. The trawls with sardines were located in the south below latitude 38.2°N (Figure 1).

Up to 50 sardines were randomly sampled from each positive trawl with more than 75 fish, or all were sampled if less than 75 fish were captured (Table 2). After the random subsample, additional mature females were randomly processed, if necessary, from the trawl catch to obtain 25 mature females per trawl for reproductive parameters or to obtain females for use in estimating batch fecundity. Each fish was sexed, standard length (mm) and weight (g) were measured, otoliths were removed for aging, tissue was preserved in 95% ethanol for genetics, and, for females, ovaries were removed and preserved in 10% neutral buffered formalin. Each preserved ovary was blotted and weighed to the nearest milligram in the laboratory. Ovary wet weight was calculated as preserved ovary weight times 0.78 (unpublished data, CDFG 1986). A piece of each ovary was removed and prepared as hematoxylin and eosin (H&E) histological slides. All slides were analyzed for oocyte development, atresia, and postovulatory follicle age to assign female maturity and reproductive state (Macewicz et al. 1996).

Daily egg production (P_0)

Because no eggs or adults were collected north of latitude 38.5°N (Calcofi line 56.7), the spawning biomass was most likely distributed in the survey area south of San Francisco. For continuity and comparison purposes, we estimated the spawning biomass for the entire survey area and for the standard DEPM survey area (i.e., the area between CalCOFI line 60 and 95) which has been surveyed for estimation of the annual spawning biomass of Pacific sardine in the past. Appropriate parameter estimates required by the DEPM were obtained for each area.

Similar to the 2001 – 2005 procedure (Lo 2001), we used a net tow as the sampling unit. Sardine eggs from CalVET tows and sardine yolk-sac larvae from both CalVET and Bongo tows in Region 1 were used to compute egg production, primarily based on data from 13 transects (Figure 1). In Region 1, a total of 36 out of 39 CalVET samples contained at least 1 sardine egg; these eggs were examined for their developmental stages (Figure 2 and Table 1). In the total Region 2 (North plus DEPM), 11 out to 125 CalVET tows caught sardine eggs.

Based on aboard-ship counts of sardine eggs in CUFES samples, 236 of the 828 collections were positive for sardine eggs over the entire survey area. For the DEPM area (south of CalCOFI line 60.0), 228 of 568 collections caught sardine eggs. In Region 1, there were 94 positive CUFES collections out of 107 total collections. In the DEPM Region 2, 134 of the total 461 collections were positive. Only eight CUFES samples taken north of CalCOFI line 60 were positive (Table 1).

For modeling the embryonic mortality curve, yolk-sac larvae (preserved larvae ≤ 5 mm notochord length) were included, and it was assumed that the mortality rate of yolk-sac larvae was the same as that of eggs (Lo 1986). Yolk-sac larval production was computed as the number of yolk-sac larvae/0.05m^2 divided by the duration of the yolk-sac stage (number of larvae/0.05m^2/day). Duration was computed based on the temperature-dependent growth curve (Table 3 of Zweifel and Lasker 1976) for each tow. For yolk-sac larvae caught by the Bongo net, larval abundance was further adjusted for size-specific extrusion from 0.505 mm mesh (Table 7 of Lo 1983) and for the percent of each sample that was sorted. The adjusted yolk-sac larvae/0.05 m^2 was then computed for each tow and was termed daily larval production/0.05 m^2.

In the whole survey area, 36 of 164 CalVET and 19 of 149 Bongo samples had at least one yolk-sac larva (Table 1). In Region 1 (Figure 3), 22 of 39 CalVET and 1 of 2 Bongo samples were positive for yolk-sac larvae (all within the DEPM area), and in the total Region 2, 14 of 125 CalVET and 18 of 147 Bongo samples were positive for yolk-sac larvae. In the DEPM survey area (area south of CalCOFI line 60), 36 out of 129 Calvet and 19 out of 116 Bongo samples had at least one yolk-sac larvae. In Region 1, 22 of 39 CalVET and 1 of 2 Bongo samples were positive for yolk-sac larvae, and in Region 2, 14 of 90 CalVET and 18 of 114 Bongo samples were positive for yolk-sac larvae (Table 1).

Daily egg production for the whole survey area (30.58°N – 48.07°N)

Because few eggs were collected in the area north of CalCOFI line 60.0 (Figure 1), the overall P_0 (daily egg production/0.05m^2) was first computed for the area south of CalCOFI line 60.0 and then prorated to the whole survey area simply by multiplying P_0 by the area south of CalCOFI line 60.0 divided by the size of the whole survey area.

Daily egg production in Region 1 ($P_{0,1}$) for the standard DEPM survey area (south of CalCOFI line 60.0)

Sardine eggs and yolk-sac larvae and their ages were used to construct an embryonic mortality curve (Lo et al. 1996). Sardine egg density for each developmental stage was computed based on CalVET samples (Figure 2). The overall density of eggs in 2010 was similar to that in recent years (Lo et al. 2009). However, unlike in most past years when stage 6 had the highest density, the density of eggs peaked at stages 6 – 9 in 2010. The next most common stages in 2010 were 5 and 11. The average sea surface temperature for CalVET tows with ≥1 egg in this DEPM survey area was 13.7°C, which is similar to that in recent years but low compared with years 2005 and 2006 (Lo et al. 2009). A temperature-dependent stage-to-age model (Lo et. al. 1996) was used to assign age to each stage. Sardine eggs and estimated ages were used directly in nonlinear regression. Eggs ≤ 3h old and eggs older than 2.5 days were excluded because of possible bias. The average sea surface temperature for all CalVET tows from *Frosti* was 12.3°C, while from the *Miller Freeman* it was 14.2°C for all tows.

The sardine embryonic mortality curve was modeled by an exponential decay curve (Lo et al. 1996):

$$P_t = P_{\mathbf{0}} e^{-zt} \qquad [1]$$

where P_t is either eggs/0.05m^2/day from CalVET tows or yolk-sac-larvae/0.05m^2/day from CalVET and Bongo tows, and t is the age (days) of eggs or yolk-sac larvae from each tow. A weighted nonlinear regression was used to estimate two parameters in equation (1) where the weights were 1/SD. The standard deviation (SD) of eggs was 3.13, 19.76, and 18.65 for day-one, day-two and day-three age groups from CalVET samples, respectively, and the SD for yolk-sac larvae was 0.31 from CalVET samples. As only one Bongo sample caught yolk-sac larvae, the SD of yolk-sac larvae from the CalVET net was used for the Bongo estimate.

A simulation study (Lo 2001) indicated that $P_{0,1}$ computed from a weighted nonlinear regression based on the original data points has a relative bias (RB) of -0.04 of the estimate, where the RB = (mean of 1,000 estimates - true value)/mean of 1,000 estimates. Therefore the bias-corrected estimate of egg production in Region 1 is calculated as $P_{0,1,c} = P_{0,1} * (1- \text{RB}) = P_{0,1} *(1.04)$, and SE ($P_{0,1,c}$) = SE($P_{0,1}$) * 1.04.

Daily egg production in Region 2 ($P_{0,2}$) for the standard DEPM survey area

Although 90 CalVET samples were taken in Region 2, only 10 tows had ≥ 1 sardine egg, ranging from 1 to 24 eggs per tow (Table 1). Therefore, we estimated daily egg production in Region 2 ($P_{0,2}$) as the product of the bias-corrected egg production in Region 1 ($P_{0,1,c}$) and the ratio (q) of egg density in Region 2 to Region 1 from CUFES samples, assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET was the same for the whole survey area:

$$P_{0,2} = P_{0,1,c}\, q \qquad [2]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}} m_i}{\sum_i m_i} \qquad [3]$$

$$\text{var}(q) = \frac{[n/(n-1)]\sum_i m_i^2 (q_i - q)^2}{\left(\sum_i m_i\right)^2}$$

where q is the ratio of eggs/min between the low density and high density areas, m_i was the total CUFES time (minutes) in the ith transect, $\bar{x}_{j,i}$ is eggs/min of the ith transect in the jth Region, and $q_i = \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}}$ is the catch ratio in the ith transect. The estimates of q were computed from a total of 10 transect lines occupied by both the *Frosti* and the *Miller Freeman*

Daily egg production (P_0) for the standard DPM survey area and for the whole survey area

P_0 was computed as the weighted average of $P_{0,1}$ and $P_{0,2}$:

$$P_0 = \frac{P_{0,1,c}A_1 + P_{0,2}A_2}{A_1 + A_2} = P_{0,1,c}w_1 + P_{0,2}w_2 = P_{0,1,c}[w_1 + qw_2] \quad [4]$$

and

$$mse(P_0) = mse(P_{0,1,c})(w_1 + w_2q)^2 + P_{0,1,c}^2 w_2^2 V(q) - mse(P_{0,1,c})w_2^2 V(q)$$

(Goodman 1960) where $mse\ (P_{0,1,c}) = v(P_{0,1}) + bias^2 = v(P_{0,1}) + (P_{0,1}\ RB)^2$
and $w_i = \frac{A_i}{A_1 + A_2}$, and A_i is the area size for i = 1 or 2.
The above P_0 was computed for the DEPM area (between CalCOFI lines 60.0 and 95). The estimate of egg production for the whole survey area, $P_{0,whole,}$ was equal to P_0 in the DEPM survey area times the ratio of the DEPM area to the whole survey area. This is equivalent to a weighted average of egg production: $P_{0,whole} = \sum P_{0,i,\ whole}\ W_{i,whole}$ where the weights are $W_{i,whole} = A_{i,whole} / A_{whole}$ for i = 1, or 2. $A_{whole} = A_{1,whole} + A_{2,\ whole}$ where $A_{i,whloe}$ is the area for the ith region in the whole survey area. For Region 1, $P_{0,1whole} = P_{0,1}$ and $P_{0,2,whole} = P_{0,2}$ x $A_{2,\ DEPM} / A_{2,\ whole} = P_{0,2,whole} = P_{0,2}$ x (244,311/449,630) where $A_{2,\ DEPM}$ is the area of the DEPM Region 2. CV $(P_{0,whole})$= se $(P_{0,whole})/ P_{0,whole}$ where se $(P_{0,whole})$ = sqrt [(se $(P_{0,1})$ * $W_{1,whole})^2$ + (se $(P_{0,2,whole})$ * $W_{2,whole})^2$]. Note that the area of Region 1 for the whole survey area $(A_{1,whole})$ is equal to Region 1 in the DEPM survey area (A_1) and CV$(P_{0,2,whole}) = $ CV$(P_{0,2})$.

Adult parameters

Four adult parameters are needed for estimation of spawning biomass: 1) daily spawning fraction or the number of spawning females per mature female per day (*S*), 2) the average batch fecundity (*F*), 3) the proportion of mature female fish by weight (sex ratio, *R*), and 4) the average weight of mature females (g, W_f). Population values for *S, R, F* and W_f were estimated using the methods of Picquelle and Stauffer (1985). Daily specific fecundity (number of eggs per population weight (g) per day) is $(RSF)/W_f$. The parameters were estimated for the whole and DEPM areas and separately for sardine females caught in each egg-density region. Correlations among all pairs of adult parameters were calculated for computing the variance of the estimate of spawning biomass (Parker 1985). In the past, the predicted batch fecundity for each female fish was calculated as y = a + bx where x is the female weight (without ovary) and y is the predicted value. In reality, most of the batch fecundities we estimated gravimetrically are scattered around the regression line and not on it. Therefore, to account for the deviation of batch fecundity from the regression line, we added an error term to the predicted value as y = a + bx + *e* where error term *e* was a random number generated from a normal distribution with mean zero and a variance of the error terms from the regression analysis. An MS[1] Visual Basic program (Chen et al. 2003) was modified to more accurately describe batch fecundity variance and was used

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

summarize the trawl adult parameters, calculate adult parameter correlations and covariance, and to estimate spawning biomass and its coefficient of variation.

Spawning fraction (S). In total, 338 mature female sardines were analyzed and considered to be a random sample of the population in the area. Histological criteria can be used to identify four different spawning nights: postovulatory follicles aged 44 – 54 hours old indicated spawning two nights before capture (A), postovulatory follicles aged about 20 – 30 hours old indicated spawning the night before capture (B), hydrated oocytes or new (without deterioration) postovulatory follicles indicated spawning the night of capture (C), and early stages of migratory-nucleus oocytes indicated that spawning would have occurred the night after capture (D). The daily spawning fraction can be estimated using the number of females spawning on one night, an average of several nights, or all nights. We used the average of the number of females identified as having spawned the night before capture (B) and those having spawned two nights before capture (A) and the adjusted number of mature females caught in each trawl (Table 2) to estimate the 2010 population spawning fraction (S_{12}) and variance (Picquelle and Stauffer 1985, Hill et al. 2009).

Batch fecundity (F). Batch fecundity (number of oocytes per spawn) was considered to be the number of migratory-nucleus-stage oocytes or the number of hydrated oocytes in the ovary (Hunter et al., 1985). We used the gravimetric method (Macewicz et al. 1996; Hunter et al. 1985, 1992) to estimate mean batch fecundity for 47 females caught during the April – May 2010 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = 5136 + 287.37W_{of}$,where $r^2 = 0.419$, variance of the slope was 2543.18, and W_{of} ranged from 75 to 152 g (Figure 4); the intercept did not differ from zero ($P = 0.418$). We used the equation $F_b = 5136 + 287.37W_{of} + e$ where the error term, e, was generated from a normal distribution with mean zero and variance of 39,573,275 to estimate batch fecundity for each of the 338 mature Pacific sardine females that were analyzed to estimate spawning frequency.

Female weight (W_f). The observed female weight was adjusted downward for females with hydrated ovaries, because their ovary weights were temporarily inflated. We obtained the adjusted female weight by the linear equation $W_f = 3.09 + 1.04W_{of}$ where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated females taken during the April 2010 CCE survey.

Sex ratio (R). The female proportion by weight was determined for each trawl (or each collection). The average weight of males and females (calculated from the first 10 males and 25 females) was multiplied by the number of males or females in the collection of 50 randomly selected fish to calculate total weight by sex in each collection. Thus, the female proportion by weight in each collection (Table 2) was calculated as estimated total female weight divided by estimated total weight in the sample. The estimate of the population's sex ratio by weight was also calculated (Picquelle and Stauffer, 1985).

Spawning biomass (B_s)

The spawning biomass was computed:

$$B_s = \frac{P_0 AC}{RSF / W_f} \qquad [5]$$

where A is the survey area in units of 0.05m^2, S is the fraction of mature females spawning per female per day, F is the batch fecundity (number of eggs per mature female released per spawning), R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (g), and C is the conversion factor from grams (g) to metric tons (mt). P_0A is the total daily egg production in the survey area, and the denominator (RSF/W_f) is the daily specific fecundity (number of eggs/population weight (g)/day).

The variance of the spawning biomass estimate $\left(\hat{B}_s\right)$ was computed using Taylor expansion and in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

$$VAR\left(\hat{B}_s\right) = \hat{B}_s^{\,2}\left[CV\left(\hat{P}_0\right)^2 + CV\left(\hat{W}_f\right)^2 + CV\left(\hat{S}\right)^2 + CV\left(\hat{R}\right)^2 + CV\left(\hat{F}\right)^2 + 2COVS\right] \qquad [6]$$

The last term, involving the covariance term, on the right-hand side is

$$COVS = \sum_i \sum_{i<j} sign \frac{COV\left(x_i, x_j\right)}{x_i x_j}$$

where x's are the adult parameter estimates, and subscripts i and j represent different adult parameters; e.g., $x_i = F$ and $x_j = W_f$. The sign of any two terms is positive if they are both in the numerator of B_S or denominator of B_S (equation 5); otherwise, the sign is negative. The covariance term is

$$\text{cov}(x_{i,} x_j) = \frac{[n/(n-1)]\sum_k m_k (x_{i,k} - x_i) g_k (x_{j,k} - x_j)}{\left(\sum_k m_k\right)\left(\sum_k g_k\right)}$$

where k refers to k^{th} tow, and k = 1,…,n. The terms of m_k and g_k are sample sizes and $x_{i,k}$ and $x_{j,k}$ are sample means from the k^{th} tow for x_i and x_j respectively.

The survey area was post-stratified into two regions based on the presence of sardine eggs: Region 1 (high-density area) and Region 2 (low-density area). Thus, equation (5) can be applied to the whole survey area and/or to each of the two regions depending on the availability of data. For the female spawning biomass (fs.biomass), one of the inputs to the stock assessment, the sex ratio (R), was excluded from equations (5) and (6). The estimate of female spawning biomass was the sum of the estimate from each of the two regions, which is referred to as the stratified procedure. The traditional method is to obtain a weighted mean for P_0 (equation 4) while each of the adult parameter was an unstratified estimate.

RESULTS

Daily egg production (P_0) for the standard DEPM survey area and the whole survey area

In Region 1, the initial daily egg production ($P_{0,1}$) from the mortality curve was 1.63/0.05 m^2/day (CV = 0.36; equation 1 and Figure 5). The bias-corrected egg production, ($P_{0,1,c}$) was 1.70 (CV = 0.36) (Table 3) for an area of 27,462 km^2 (south of CalCOFI line 60.0). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.128 (CV=0.37) (equation 3). For the DEPM area Region 2, the egg production ($P_{0,2}$) was 0.217 /0.05 m^2/day (CV = 0.5) for an area of 244,311 km^2 (71,384 nm^2). The estimate of the daily egg production was 0.367/0.05 m^2 (CV = 0.4) (equation 4) for 271,773 km^2 (79,407 nm^2) (Table 3). Egg mortality (0.33 (CV=0.23)) was similar to many years (Table 4). The P_0 for the whole Region 2 was 0.12 (CV=0.5). The P_0 for the whole survey area was 0.21/0.05 m^2/day (CV=0.32)

Catch ratio between CUFES and CalVET (E)

Although this ratio is no longer needed in the current estimation procedure, we computed it for comparison purposes. The catch ratio of eggs/min to eggs/tow (eggs/min = E * eggs/0.05 m^2) was computed from 46 pairs of CalVET tows and CUFES collections from the *Frosti* and *Miller Freeman* cruises (Figure 6). The eggs/min corresponding to each positive CalVET tow was the mean of all CUFES collections taken from one hour before to one hour after each positive CalVET tow. The catch ratio was 0.077 (CV=0.14) in comparison to the 2009 estimate of 0.158 (CV=0.12), 2008 estimate of 0.19 (CV=0.06), 2007 estimate of 0.15 (CV=0.09), the 2006 estimate of 0.32(CV=0.12), the 2005 estimate of 0.18 (CV = 0.28), the 2004 estimate of 0.22 (CV = 0.09) and the 2003 estimate of 0.39 (CV = 0.11). A ratio of 0.077 means that one egg/tow from a CalVET tow was equivalent to approximately 0.077 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 12.98 eggs/tow from the CalVET sample.

Adult parameters

Over the whole survey area trawled (31.16° – 47.66°N) during the April 2010 CCE survey, only one tow caught sardines north of CalCOFI line 60 at 38.19°N and 17 of 18 positive tows contained female sardines in the standard DEPM survey area off California (from CalCOFI lines 95 to 60). Standard length (SL), of the randomly obtained sardine in each trawl ranged from 128 to 265 mm for 290 males and from 143 to 262 mm for 395 females. The smallest mature female was 164 mm SL. The length at which 50% of females are mature (ML_{50}) was not calculated because only 5 immature female sardines (size range 143 to 173 mm SL) were captured in the survey.

The DEPM survey area off California in 2010 was 271,773 km^2. Estimates of reproductive parameters of 313 mature female sardines (up to 25 mature analyzed per trawl) for the individual trawls are given in Table 2. The mature female Pacific sardine reproductive parameters in the standard DEPM survey area, estimated from 17 positive trawls and 313 mature females, were: *F*, mean batch fecundity, 39,304 eggs/batch (CV = 0.03); *S*, fraction spawning per day, 0.104 females spawning per day (CV = 0.22); W_f, mean female fish weight, 129.5 g (CV = 0.02); and *R*, sex ratio of females by weight, 0.574 (CV = 0.07) (Table 5). The average interval between spawning (spawning frequency) was about 10 days (inverse of spawning fraction or 1/0.104), and the daily specific fecundity was 18.07 eggs/population weight (g)/day (Table 5). The correlation matrix for the adult parameter estimates for Region 1, Region 2 within DEPM area, and the whole DEPM area is shown in Table 5. We also provided estimates of each adult parameter in each region (Table 5), primarily because they are used to compute female spawning biomass which is an input to stock assessment.

Over the whole survey area (477,092 km^2), the single positive collection north of CalCOFI line 60 (collection 2618, Table 2) was included in estimation of reproductive parameters; 338 mature female sardines were analyzed. The estimate of the April 2010 population sex ratio (*R*), was 0.586 (CV = 0.06) (Table 6). Estimates of the other female sardine parameters were: *F*, mean batch fecundity, 39,741 eggs/batch (CV = 0.04); *S*, spawning fraction, 0.112 per day (CV = 0.21); and W_f, mean female fish weight, 131.3 grams (CV = 0.02). The average interval between spawning (spawning frequency) was about 9 days (inverse of spawning fraction or 1/0.112), and the daily specific fecundity was 19.92 eggs/population weight (g)/day. The correlation matrix for the adult parameter estimates over the whole survey area is shown in Table 6.

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardine in 2010 using the traditional method (equation 1 and 4, Table 3 and 4) was 108,280 mt(CV=0.46) or 119,108 short tons(st) (=mt x 1.1) for the standard DEPM survey area of 271,773 km^2 (79,839 nm^2) off California. The point estimate of spawning biomass of Pacific sardine off California in 1994 – 2010 are, respectively, 127,102;79,997; 83,176; 409,579; 313,986; 282,248; 1,063,837; 790,925; 206,333; 485,121; 281,639; 621,657; 837,501; 392,492, 117,426, 185,084, and 108,280 mt (Table 4). For the entire survey area of 477,092 km^2 (139,106 nm^2) from San Diego to Cape Flatttery, Washington, the point estimate of spawning biomass was 100,578 mt (CV = 0.38). Based on the stratified procedure, the estimate of spawning biomass was 105,220 mt (CV = 0.4) and 96,622 mt (CV = 0.38) for the DEPM area and the entire survey area respectively (Table 3 and 7).

The estimate of the female spawning biomass for the DEPM survey area was 58,447mt (CV = 0.42) and 62,131 mt (CV = 0.46) based on the stratified procedure and the traditional method respectively. The former with estimates of previous years was used as one input time series to the Pacific sardine stock assessment (Table 7). The point estimates of spawning biomass for the DEPM area were greater than those for the entire survey area. However the differences were not statistically significant.

DISCUSSION

Sardine eggs

Sardine eggs in April 2010 were concentrated in the area between CalCOFI lines 63.3 and 73.3 up to offshore station 90.0 in a small area (Figure 1) compared to the egg distribution in 2009 when eggs were distributed south between CalCOFI lines 81.7 and 95.0 (Lo et al. 2009). The change in distribution could be due to low water temperature or other environmental conditions. The area north of CalCOFI line 60.0 had few eggs, and no eggs were observed north of Calcofi line 56.7. The daily egg production rate of 1.70 in the high-density area was similar to those of 2009 and 2008. However, the high-density area was only 10% of the DEPM survey area, much lower than in previous years (e.g., 27% in 2009). Thus, the low overall P_0 for the standard DEPM survey area was primarily due to the small Region 1, the high spawning area. The spawning area has been in the southern part of California waters since 2006 even though a few eggs were observed in Mexican surveys, i.e. IMCECOCAL. In the past, the years when eggs were concentrated north of Point Conception were 1999, 2004 and 2005. The small size of Region 1 in 2010 and its northern location (between CalCOFI line 63.3 and 73.3) could be due to minor La Niña phenomena. Moreover, in 2006 CCE survey, eggs were observed around latitudes 40 – 43^{o}N, which was not true for the 2008 and the 2010 CCE surveys.

The adaptive allocation sampling procedure was used aboard the *Frosti* and the *Miller Freeman*. Due to the low egg density, only 129 CalVET tows were taken in the standard DEPM survey area. This was lower than 136 in 2009, higher than the 84 in 2007, 123 in 2006, 74 in 2005, and 124 tows in 2004, but smaller than in other recent years: 217 in 2002, 192 in 2003 and 151 in 2008. We highly recommend that adaptive allocation sampling be applied aboard the research vessel that conducts the spring (March – April) routine CalCOFI survey in the future to enhance the quality of the estimate of the spawning biomass. Because the CalCOFI spring cruise was conducted from April 26 – May 17, 2010 after the CCE survey, the egg and larval data from the CalCOFI April cruise were not included in the computation of egg production.

Embryonic mortality curve

The estimates of the daily egg production at age 0 (P_0/0.05 m^2=1.63) and the daily embryonic mortality (0.33, CV = 0.23) from the mortality curve in Region 1 were similar to those in 2009 but lower than in previous years. The low value of P_0 was partially caused by the distribution of egg developmental stages (Figure 2). In many past years, the peak egg developmental stage was stage 6. In 2010, the peak densities spread from stage 6 to 9. The latter phenomenon is not understood and needs thorough investigation. The overall P_0 in the DEPM (0.36 eggs/0.05m^2) and the entire survey area (0.21 eggs/0.05m^2) were lower than previous years (Table 3 and 4), partially due to the small size of the high-density area (Figure 1).

Catch ratio between CUFES and CalVET (E)

The 2010 catch ratio between CUFES and CalVET (0.077) computed from data obtained from the *Frosti* and *Miller Freeman* appeared to be lowest among all years: 2009 (0.15), 2008 (0.14), 2007 (0.15), 2006 (0.32(CV = 0.12)), 2005 (0.18 (CV = 0.28)), 2004 (0.22 (CV = 0.09)), 2003 (0.39 (CV = 0.11)), 2002 (0.24 (CV = 0.06)), 2001 (0.145 (CV = 0.026)), 2000 (0.27), 1999 (0.34), and 1998 (0.32). This low catch ratio in 2010 indicated that fewer eggs were in the upper 3 meters of the water column, possibly due to weakly mixed ocean water. Again, the current catch ratio is different from the 1996 estimate of 0.73. This could be because the 1996 CalVET samples were taken only in the southern area near San Diego (routine CalCOFI survey area) while after 1997 CalVET samples were taken in a larger area extending far north of San Diego (Lo et al. 2005). It would be informative to examine the relationship between the catch ratio and the degree of water mixing over the years (Lo et al. 2001).

The ratio of egg densities of two regions from pump samples (q)

The q value (ratio of eggs/min in Region 1 to eggs/min in Region 2) serves as the calibration factor to estimate $P_{0,2}$ in Region 2 (equation 2), because low abundance of eggs observed in Region 2 prevents us from using the egg mortality curve to directly estimate $P_{0,2}$. For the 2010 survey, q was obtained from 10 transect lines between CalCOFI lines 78.3 and 60.0 including transit lines; it was 0.128 (CV = 0.37) for the standard DEPM sampling area. This value, even though lower than that of 2007 (0.48), was higher than those of previous years. The q values have ranged from 0.036 to 0.065 since 2001 with an increasing trend. If this trend continues, it may mean that the spatial distribution of the sardine eggs is becoming less aggregated.

Adult parameters

Trawling during the April 2010 CCE survey again covered a large area off the west coast of the U.S. from Cape Flattery, WA to San Diego, CA. Previous trawling was conducted in the spring off the whole west coast during 2006 and 2008 (Lo et al. 2007a, 2008). We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in three subareas off the coast: Washington and Oregon (9.5 – 11.4^{o}C), northern CA (9.6 – 13.2^{o}C), and the standard DEPM area (12.1 – 15.9^{o}C). The 2010 temperature ranges were warmer than those during 2008, and while similar to the warmer temperatures in 2006, no eggs or adults were found off Washington and Oregon in 2010 (Table 8). In all three surveys, sardines sampled were larger in the northern CA area than in the standard DEPM area. In the standard DEPM area, sardine adults and eggs were always collected, and although the size of sardines caught has increased from 67g in 2006 to 105g in 2008 and to 127g in 2010, the size of Region 1 (high sardine egg density) and P_0 (daily egg production) has decreased during this period of time (Table 8). This trend in the DEPM area coupled with the decrease in the spawning biomass since 2006 (Table 4) may indicate decreasing recruitment of recent year classes.

During the April 2010 survey in the standard DEPM survey area, we were again able to collect some trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) sardine egg density to yield a better estimate of Pacific sardine spawning biomass for the whole population in the large oceanic area from San Diego to San Francisco. We found that the average mature female weight (W_f) was similar in both regions (133.6 grams (SE = 2.46) in Region 1 and 128.5 grams (SE = 2.28) in Region 2, Table 5) while the fraction of females spawning per day, S_{12}, (based on the average of females that spawned the night before capture and 2 night before capture or "average of day 1+day 2") was higher in Region 1 (0.165 females/day (CV = 0.15)) than Region 2 (0.088 females/day (CV = 0.3)) and this difference in the fraction of females spawning was close to being statistically significant ($t = 2.19$, $df = 8$, $0.05<p<0.1$). This regional difference in the fraction of females spawning (high in 1 and lower in 2) was similar to that in past DEPM surveys in 2005, 2006 (Lo and Macewicz 2006, Lo et al. 2007a), 2007 (when one unusual trawl is removed, Lo et al. 2007b), 2008, and 2009 (Lo et al. 2008, 2009). Because more females were spawning per day in Region 1 than Region 2, it is necessary to continue to trawl in both regions to ensure an unbiased estimate of spawning biomass for the whole population.

In 2010 the CV (0.22) of the spawning fraction estimate in the DEPM area was higher than that in 2009 (CV = 0.15) but lower than those in earlier years (CVs of 0.33 in 2007 and 0.31 in 2005 and 2008) (Lo et al. 2006, 2007b, 2008 and 2009). The high CVs in previous years were most likely due to the low number of sardine positive trawls (12 – 14) and high variability of spawning (Table 9). In 2010, as in 2009, a factor in improvement of the CV was the change in the calculation of daily spawning fraction. In the past (1994, 1997, 2004, 2005, 2007, and 2008), calculation of the original daily spawning fraction (S_1) was based on the number of females that spawned the night before capture (night B, "day1") and followed the procedure for Northern anchovy (Picquelle and Hewitt, 1983) to replace the number of females spawning the night of capture (night C, "day0") with the number of night B spawning females to adjust the number of total mature females. By contrast, in 2009 we calculated the daily spawning fraction (S_{12}) using the mean number of night B and night A (two nights before capture, "day2") spawning females for each trawl and replaced the night C females by this mean to adjust the number of total mature females. Another factor for the low CV of the 2009 spawning fraction estimate was an increase in the number of trawls with sardine (29). Although we increased the total number of night-time trawls to 65 in the DEPM area, only 17 caught sardine females and, thus, the relatively low CV (0.22) in 2010 was likely due to the change in the estimation of spawning fraction (S_{12}). Therefore for continued improvement of spawning fraction precision, we recommend using S_{12} to calculate daily spawning fraction and that at least 17 trawl samples need to be obtained or the number of trawls sampled be increased, in both high and low egg density areas, for future biomass surveys.

We examined the sardines taken in 2010 and compared them to those taken during a similar period in the standard DEPM area in 2009 and 2008. The mean size of sardines (male and females) was slightly larger than in 2008 and 2009 (Figure 7). There were very few 175 mm to 194 mm SL sardines in 2010, some in 2009, and more in 2008. Few immature females were found in the 3 surveys (5 in 2010, 1 in 2009, and none in 2008). We believe the scarcity of immature females could possibly be due to: 1) poor recruitment in recent years, 2) the fact that most trawls captured sardines in offshore areas where sardines are known to be large relative to inshore (Lo et al. 2007), and/or 3) because of reduced effort in inshore areas to avoid marine mammals. Port samples or samples from observers on commercial vessels could obtain the smaller fish that predominately occur inshore for maturity information but, generally, these samples are not properly preserved and could not be used for estimation of daily spawning fraction which requires histological analysis. We recommend that to improve the whole population adult parameter analyses more trawls should be added in the inshore areas to obtain spawning and maturity information on smaller fish to avoid possible bias against smaller fish.

Spawning biomass

In the DEPM survey area the 2010 estimate of spawning biomass using the traditional method was 108,280 mt, based on the egg production of 0.36 eggs/0.05m$^{2/}$day, and the daily specific fecundity of 18.07 eggs/g/day. This production was primarily in the area between 34°N and 38°N. The spawning biomass was considerably lower than for most previous years (Table 4). The low spawning biomass is primarily due to the small size of the high-density area (Table 4) and an above average adult reproductive output (Table 3). Note that the egg production rate of 1.70 eggs/0.05m^2 in the high-density area was similar to that of 2009: 1.69 eggs/.05m^2 (Lo et al. 2009). The daily egg production, 0.36 eggs/0.05m^2/day, was lower than in most years: 0.59 in 2009, 0.43 in 2008, 0.864 in 2007, 1.936 in 2006, and 1.916 eggs/0.05m^2 in 2005. The area of Region 1 of 27,462 km^2 was the smallest of all years. The adult daily reproductive output (daily specific fecundity) was similar to that in the previous year. The higher values in early years were due to the fact that trawl samples were taken in the high-density area only. Since 2005, trawl samples have been taken in both Region 1 and Region 2. In 2010 more positive trawls were taken in Region 2 than Region 1. The low egg production rate and the high value of the daily specific fecundity (18.07) may indicate that the adults were survivors of the strong 2003 year class and that there have been low incoming classes since 2003. The point estimates of total spawning biomass for the DEPM survey area were greater than those for the whole survey area using either the traditional method or the stratified procedure. The difference was due to one positive trawl taken north of the DEPM survey area (Table 2). This trawl contained a high number of spawning females which were large and most likely migrants (Table 2) and, thus, including this trawl sample in the computation resulted in an estimate of daily specific fecundity for the whole area (19.92) higher than for the DEPM area (18.07). However, the differences of spawning biomass between the DEPM survey area and the entire survey area were not statistically significant due to the CV values. For the stock assessment, we provided the estimates of female spawning biomass for years where adequate adult samples were available (Table 4 and 7).

ACKNOWLEDGMENTS

We especially want to thank the crew members of the NOAA ship *Miller Freeman* and the chartered fishing vessel *Frosti*. Eggs, larvae, and adult sardines were collected aboard the *Frosti* by Amy Hays, Sue Manion, Dimity Abramenkoff, Marisa Litz, Kyle Byers, Eric Lynn, William Watson, and Andrew Claiborne and aboard the *Miller Freeman* by Sherri Charter, Ed Weber, Nancy McGehee, Andrew Thompson, Ofelia Ramirez, Debra Winter, and Robin Gartman. William Watson's lab staged sardine eggs and Erin Reed processed preserved ovaries. We greatly appreciate Andrew Thompson and Ed Weber for reading the manuscript.

REFERENCES

Barnes, J. T., M. Yaremko, L. Jacobson, N.C.H. Lo, and J. Stehly. 1997. Status of the Pacific sardine (*Sardinops sagax*) resource in 1996. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-237.

Checkley, D. M. Jr., P. B. Ortner, L. R. Settle, and S.R. Cummmings. 1997. A continuous, underway fish egg sampler. Fish. Oceanogr. 6(2):58-73.

Chen, H, N. Lo, and B. Macewicz. 2003. MS ACCESS programs for processing data from adult samples, estimating adult parameters and spawning biomass using daily egg production method (DEPM). Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-03-14. 17 pp, Appendices 63pp.

Goodman, L. A. 1960. On the exact variance of products. Journal of American Statistical Association, 55(292):708-713.

Hill, K. T., M. Yaremko, L. D. Jacobson, N. C. H. Lo, and D. A. Hanan. 1998. Stock assessment and management recommendations for Pacific sardine in 1997. Marine Region, Admin. Rept 98-5. California Department of Fish and Game.

Hill, K. T., L. D. Jacobson, N. C. H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine for 1998 with management recommendations for 1999. Marine Region, Admin. Rep 99-4. California Department of Fish and Game.

Hill, K.T., N.C.H. Lo, B. J. Macewicz and R. Felix-Uraga. 2006a.Assessment of the Pacific sardine (*Sardinops sagax caeurulea*) population for U.S. management in 2006. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-386.

Hill, K.T., N.C.H. Lo, B. J. Macewicz and R. Felix-Uraga. 2006b.Assessment of the Pacific sardine (*Sardinops sagax caeurulea*) population for U.S. management in 2007. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-396.

Hill, K.T., N.C.H. Lo, B. J. Macewicz and Paul R. Crone. 2009. Assessment of the Pacific sardine (*Sardinops sagax caeurulea*) population for U.S. management in 2010. STAR Panel Review Draft.

Hunter, J. R., N. C. H. Lo, and R. J. H. Leong. 1985. Batch fecundity in multiple spawning fishes. *In* An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*, R. Lasker, ed. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 36, pp.67-77.

Hunter, J. R., B. J. Macewicz, N. C. H. Lo, and C. A. Kimbrell. 1992. Fecundity, spawning, and maturity of female Dover sole *Microstomus pacificus,* with an evaluation of assumptions and precision. Fish. Bull. 90:101-128.

Lasker, R. 1985. An egg production method for estimating spawning biomass of northern anchovy, *Engraulis mordax*. U.S. Dep. Commer., NOAA Technical Report NMFS 36, 99pp.

Lo, N.C.H. 1983. Re-examination of three parameters associated with anchovy egg and larval abundance: temperature dependent incubation time, yolk-sac growth rate and egg and larval retention in mesh nets. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-31, 32 p

Lo, N.C.H. 1986. Modeling life-stage-specific instantaneous mortality rates, an application to Northern anchovy, *Engraulis mordax,* eggs and larvae. U.S. Fish. Bull. 84(2):395-406

Lo, N. C. H. 2001. Daily egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2001. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-01-08. 32 pp.

Lo, N. C. H. 2003. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2003. Southwest fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-03-11. 17 pp.

Lo, N. C. H., Y. A. Green Ruiz, M. J. Cervantes, H. G. Moser, and R. J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) in 1994, determined by the daily egg production method. Calif. Coop. Oeanic. Invest. Rep. 37:160-174.

Lo, N.C.H., J. R. Hunter, and R. Charter. 2001. Use of a continuous egg sampler for ichthyoplankton survey: application to the estimation of daily egg production of Pacific sardine (*Sardinops sagax*) off California. Fish. Bull. 99:554-571.

Lo, N. C. H. and B. Macewicz. 2004. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2004 and 1995. Southwest fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-04-08. 30 pp.

Lo, N. C. H., B. J. Macewicz, and D. A. Griffith. 2005. Spawning biomass of Pacific sardine (*Sardinops sagax*), from 1994-2004, off California. Calif. Coop. Oeanic. Invest. Rep. 46:93-112.

Lo, N. C. H. and B. J. Macewicz. 2006. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2005. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-387. 29 pp.

Lo, N. C. H., B. J. Macewicz, D. A. Griffith and Richard L. Charter. 2007a. Spawning biomass of Pacific sardine (*Sardinops sagax*) off U.S. and Canada in 2006. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-401. 32 pp.

Lo, N. C. H., B. J. Macewicz, D. A. Griffith and Richard L. Charter. 2007b. Spawning biomass of Pacific sardine (*Sardinops sagax*) off U.S. and Canada in 2007. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-411. 31 pp.

Lo, N. C. H., B. J. Macewicz, D. A. Griffith and Richard L. Charter. 2008. Spawning biomass of Pacific sardine (*Sardinops sagax*) off U.S. and Canada in 2008. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-430. 33 pp

Lo, N. C. H., B. J. Macewicz, and D. A. Griffith. 2009. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2009. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-449. 31 pp.

.

Macewicz, B. J., J .J. Castro-Gonzalez, C. E. Cotero Altamrano, and J.R. Hunter. 1996. Adult reproductive parameters of Pacific Sardine (*Sardinops sagax*) during 1994. Calif. Coop. Oeanic. Invest. Rep. 37:140-151.

Parker, K. 1985. Biomass model for egg production method. *In* An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*, R. Lasker, ed. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 36, pp. 5-6.

Picquelle, S. J., and R. P. Hewitt. 1983. The northern anchovy spawning biomass for the 1982-1983 California fishing season. Calif. Coop. Oeanic. Invest. Rep. 24:16-28.

Picquelle, S., and G. Stauffer. 1985. Parameter estimation for an egg production method of northern anchovy biomass assessment. *In* An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*, R. Lasker, ed. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 36, pp. 7-16.

Scannel, C. L., T. Dickerson, P. Wolf, and K. Worcester. 1996. Application of an egg production method to estimate the spawning biomass of Pacific sardines off southern California in 1986. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-96-01. 37 pp.

Wolf, P. 1988a. Status of the spawning biomass of Pacific sardine, 1987-1988. Calif. Dep. Fish. Game, Mar. Res. Div., Rep. to the Legislature, 9 pp.

Wolf, P. 1988b. Status of the spawning biomass of Pacific sardine, 1988-1989. Calif. Dep. Fish. Game, Mar. Res. Div., Rep. to the Legislature, 8 pp.

Zweifel, J. R., and R. Lasker. 1976. Prehatch and posthatch growth of fishes - a general model. Fish. Bull. 74(3):609-621.

Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, eggs from CUFES and positive sardine trawls[a] in Region 1 (eggs/min ≥ 1), Region 2 (eggs/min < 1) for *Frosti* , and *Miller Freeman* cruises of 2010 April CCE survey. Both *Miller Freeman* and *Frosti* occupied part of the standard DEPM survey area: *Miller Freeman* occupied the area from CalCOFI line 95.0 to 66.7. *Frosti* occupied the area from Cape Flattery, Washington to CalCOFI line of 70.0). The area north of CalCOFI line 60.0 is referred to as 'North' and the standard DEPM survey area is CalCOFI line 95.0 – 60.0.

		Region 1			**Region 2**			**Grand Total**		
		Total	North	DEPM	Total	North	DEPM	Total	North	DEPM
CalVET Eggs	Positive	36	0	36	11	1	10	47	1	46
	Total	39	0	39	125	35	90	164	35	129
CalVET Yolk-sac	Positive	22	0	22	14	0	14	36	0	36
	Total	39	0	39	125	35	90	164	35	129
Bongo Yolk-sac	Positive	1	0	1	18	0	18	19	0	19
	Total	2	0	2	147	33	114	149	33	116
CUFES Eggs	Positive	94	0	94	142	8	134	236	8	228
	Total	107	0	107	721	260	461	828	260	568
Trawls	Positive	3	--	3	16	1	15	19	1	18
	Total	11	--	11	87	29	58	98	29	69

[a] None of the eight daytime tows caught sardines, all sardines were captured at night.

Table 2. Sardine egg density region, individual trawl information, sex ratio[a], and parameters for mature female sardine, *Sardinops sagax*, used in the estimation of the April 2010 west coast spawning biomass. Collection 2618 is north of CalCOFI line 60 and the other 18 trawls are in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES							
				Location										Number spawning		
Region 1=high 2=low	No.	Month -Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	No. of fish	Sex Ratio	No. analyzed [b]	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	Adj. No.[c]	Night of capture	Night before capture	2 Nights before capture
2	2618	4-15	20:36	38.194	124.070	13.2	50	0.712	25	153.94	144.64	45215	24.5	6	3	8
2	2626	4-17	19:54	37.609	123.656	13.3	38	0.655	24	128.96	121.61	38918	22.5	4	3	2
2	2628	4-18	3:48	37.419	123.346	12.8	1	0.000	0	0.00	0.00	0	0.0	0	0	0
2	2644	4-27	3:04	36.992	124.397	13.1	50	0.605	25	121.02	111.65	35430	25.0	0	0	0
2	2642	4-26	19:56	36.992	123.772	12.8	2	0.530	1	132.00	119.20	30499	1.0	0	0	0
2	2630	4-18	20:27	36.984	123.333	13.5	50	0.727	25	134.59	125.95	40518	24.0	2	1	1
2	2643	4-27	0:02	36.972	124.109	13.2	9	0.652	5	109.50	100.69	31427	5.0	0	0	0
1	2631	4-18	23:42	36.812	123.687	13.7	50	0.648	25	137.07	129.64	44069	29.0	1	6	4
2	2632	4-19	2:55	36.733	123.868	14.0	50	0.526	25	133.56	123.36	39929	23.5	2	0	1
2	2579	4-18	20:10	36.435	122.743	13.7	50	0.637	25	119.46	111.60	35981	23.5	2	0	1
2	2681	4-19	0:41	36.338	122.954	13.6	38	0.705	24	120.71	113.60	35501	24.0	0	0	0
2	2682	4-19	2:50	36.288	123.098	13.6	29	0.541	14	131.50	124.34	42977	14.5	2	3	2
2	2634	4-20	0:21	35.922	124.799	14.4	39	0.442	17	143.09	132.19	44153	16.5	1	0	1
2	2577	4-18	2:50	35.855	122.149	12.8	27	0.584	16	117.78	112.29	35361	21.0	0	5	5
2	2685	4-19	19:47	35.820	124.189	15.0	50	0.521	25	131.84	124.15	40178	23.5	7	5	6
2	2686	4-19	23:58	35.697	124.339	14.7	50	0.716	25	136.38	128.46	41722	28.0	1	2	6
1	2576	4-17	23:50	35.617	121.886	13.2	36	0.498	17	128.71	120.79	39866	18.0	1	1	3
2	2687	4-20	2:27	35.613	124.525	14.4	4	0.543	2	135.25	128.59	33811	2.5	0	1	0
1	2562	4-12	23:52	33.840	120.913	12.5	62	0.300	18	133.31	124.78	39967	16.5	5	2	5
									338				342.5	34	32	45

[a] Sex ratio, proportion of females by weight, based on average weights from subsamples and number of fish sampled in each trawl(Picquelle and Stauffer 1985).

[b] For the whole survey, 338 females were analyzed histologically and 313 of those females were from the DEPM area

[c] Mature adjusted by the average number of females spawning the night before capture and females spawning 2 nights before capture

Table 3. Egg production (P_0) of the Pacific sardine in 2010 based on egg data from CalVET and yolk-sac larval data from CalVET and Bongo in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1) from *Frosti* (March 28 – April 28), and *Miller Freeman* (April 2 – 22) cruises, adult parameters from positive trawls (April 12 – 27), and 2010 spawning biomass estimates.

Parameter	**Region 1**	**Region 2**			**DEPM Area**	Whole Area
		North	DEPM	Total		
CUFES samples	107	260	461	721	**568**	828
CalVET samples	44	35	85	120	**129**	164
P_0 / 0.05m^2	1.70 [a]	0	0.22	0.12	**0.36**	0.21
CV	0.36	--	0.50	0.50	**0.40**	0.32
Area (km^2)	27,462	205,319	244,311	449,630	**271,773**	477,092
% Whole coast	5.7	43	51.3	94.3	**57**	100
% DEPM area	10	--	90	--	**100**	--
Year of adult samples	2010	2010	2010	2010	**2010**	2010
Female fish wt (W_f)	133.6	153.94	128.54	130.83	**129.51**	131.31
Batch fecundity (F)	41647	45215	38748	39330	**39304**	39741
Spawning fraction (S)	0.165	0.22	0.088	0.100	**0.104**	0.112
Sex ratio (R)	0.466	0.712	0.608	0.619	**0.574**	0.586
(RSF)/W_f	24.02	46.01	16.20	18.69	**18.07**	19.92
Spawning biomass (mt) Traditional method [b]					**108,280**	100,578
CV					**0.46**	0.38
Spawning biomass (mt) Stratified procedure [c]	38,875		66,345	57,747	**105,220**	96,622
CV	0.44		0.58	0.57	**0.4**	0.38
Daily mortality (Z)	0.33					
CV	0.23					
eggs/min	2.7		0.20		**0.45**	
CV	0.43		0.61		**0.36**	
q = eggs/min in Reg.2 / eggs/min in Reg.1					**0.128**	0.128
CV					**0.37**	0.37
E = (eggs/min)/(eggs/tow)					**0.077**	0.077
CV					**0.14**	0.14
Bongo samples	2	33	114	147	**116**	149
Area in nm^2	8,024	59,990	71,383	131,373	**79,407**	139,397
Spawning biomass (short ton)	42,762	--	72,980	63,522	**119,108**	110,636

[a] 1.70 was corrected for bias of P_0.
[b] biomass was computed from estimates of parameters in each column, e.g., DEPM area is an average of adult parameters from Region 1 and DEPM Region 2, and Whole area is the average from Region 1 and Total Region 2.
[c] biomass was computed by the stratified procedure, i.e., total spawning biomass = the sum of the estimates of spawning biomass in Region 1 and Region 2, e.g. 105,220 = 38,875+66,345; 96,622 = 38,875+57,747

Table 4. Estimates of daily egg production (P_0)[a] for the DEPM survey area, daily instantaneous mortality rates (Z) from high-density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardines using the traditional method and average sea surface temperature for the years 1994 to 2010.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	$\frac{RSF^h}{W}$	Spawning biomass (mt) (CV)[b]	Mean Temp. for positive egg or yolk-sac samples	Mean temperature all CalVETs
1994	0.193 (0.210)	0.120 (0.91)	380,175 (174,880)	11.38	127,102 (0.32)	14.3	14.7
1995	0.830 (05)	0.400 (0.4)	113,188.9 (113188.9)	23.55[c]	79,997 (0.6)	15.5	14.7
1996	0.415 (0.42)	0.105 (4.15)	235,960 (112,322)	23.55	83,176 (0.48)	14.5	15.0
1997	2.770 (0.21)	0.350 (0.14)	174,096 (66,841)	23.55[d]	409,579 (0.31)	13.7	13.9
1998	2.279 (0.34)	0.255 (0.37)	162,253 (162,253)	23.55	313,986 (0.41)	14.38	14.6
1999	1.092 (0.35)	0.100 (0.6)	304,191 (130,890)	23.55	282,248 (0.42)	12.5	12.6
2000	4.235 (0.4)	0.420 (0.73)	295,759 (57,525)	23.55	1,063,837 (0.67)	14.1	14.4
2001	2.898 (0.39)	0.370 (0.21)	321,386 (70,148)	23.55	790,925 (0.45)	13.3	13.2
2002	0.728 (0.17)	0.400 (0.15)	325,082 (88,403)	22.94	206,333 (0.35)	13.6	13.6
2003	1.520 (0.18)	0.480 (0.08)	365,906 (82,578)	22.94	485,121 (0.36)	13.7	13.8
2004	0.960 (0.24)	0.250 (0.04)	320,620 (68,234)	21.86[e]	281,639 (0.3)	13.4	13.7
2005	1.916 (0.417)	0.579 (0.20)	253,620 (46,203)	15.67	621,657 (0.54)	14.21	14.1
2006	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	15.57[f]	837,501[f] (0.46)	14.95	14.5
2007	0.864 (0.256)	0.133 (0.36)	356,159 (142,403)	15.68	392,492 (0.45)	13.7	13.6
2008[g]	0.43 (0.21)	0.13 (0.29)	297,949 (53,514)	21.82	117,426 (0.43)	13.3	13.1
2009	0.59 (0.22)	0.25 (0.19)	274895 (74966)	17.53	185,084 (0.28)	13.6	13.5
2010[i]	0.36 (0.40)	0.33 (0.23)	271,773 (27,462)	18.07	108,280 (0.46)	13.7	13.9

a weighted non-linear regression on original data and bias correction of 1.04, except in 1994 and 1997 when grouped data and a correction factor of 1.14 was used (appendix Lo 2001).

b $CV(B_s) = (CV^2(P_0) + \text{allotherCOV}^2)^{1/2} = (CV^2(P_0)+0.054)^{1/2}$. For years 1995 – 2001 allotherCOV^2 was from 1994 data (Lo et al. 1996). For year 2003, allotherCOV was from 2002 data (Lo and Macewicz 2002)

c 23.55 was from computation for 1994 based on S = 0.149 (the average spawning fraction (day 0 + day 1) of active females from 1986 – 1994; Macewicz et al. 1996).

d is 25.94 when calculated from parameters in 1997 (table 9) and estimated spawning biomass is 371,725 mt with CV = 0.36

e uses R = 0.5 (Lo and Macewicz 2004); if use actual R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt

f value for standard DEPM sampling area off California when calculated using S = 0.126, the average of females spawning the night before capture ("day 1") from 1997, 2004, 2005, and 2007. When 2006 survey S of 0.0698 was previously used (Lo et al. 2007a), the 2006 DEPM spawning biomass was estimated as 1,512,882 mt (CV 0.46) and the 2006 coast-wide spawning biomass was estimated as 1,682,260 mt

g standard DEPM sampling area off California from San Diego to CalCOFI line 66.7 whole 2008 survey area off west coast of North America from about 31°N to 48.47°N latitude, spawning biomass was estimated as 135,301 mt(CV=0.43)

h RSF/W from 2009 is based on S_{12},:average of day1 and day2 females.

i The whole survey area was 477092 km^2 from San Diego, CA to Cape Flattery,Wa. .Very few sardine eggs were observed north of the DEPM survey area (CalCOFI line 60.0 is the northern boundary of the DEPM area)

Table 5. Estimated 2010 adult parameters and correlations for each region[a] in the DEPM area outputted from the EPM program (Appendix II Chen et al. 2003).

Region 1 for DEPM and whole survey area

Statistic Results:

	Average	Variance
Whole Body Weight	133.576197333	6.0444339346
Gonad Fee Weight	125.676066667	7.08378134307
Batch fecundity	41647.4256443	2290079.15300
Spawners, Day 0	0.11666666667	0.00543773148
Spawners ave (Day 1 + Day2)	0.16535433858	0.00059173270
Sex Ratio	0.46587630644	0.01359604451
Daily specific fecundity	24.0184680578	
Number of Sets	3	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.88950829	0.62484612	0.46178964
Batch Fecundity (F)			0.19906722	0.81604808
Fraction Spawning (S)				-0.4039677
Sex Ratio (R)				

Region 2 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	128.542520791	5.18041962778
Gonad Fee Weight	120.311600791	4.50676785646
Batch fecundity	38748.2629683	1953143.02487
Spawners, Day 0	0.08300395257	0.00068265872
Spawners ave (Day 1 + Day2)	0.08840875639	0.00070641051
Sex Ratio	0.60797953654	0.00083643664
Daily specific fecundity	16.2027850115	
Number of Sets	14	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.96234178	0.19601070	-0.2063412
Batch Fecundity (F)			0.31323327	-0.2415580
Fraction Spawning (S)				-0.1408787
Sex Ratio (R)				

DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	129.507442812	3.82067689927
Gonad Fee Weight	121.339932907	3.46545757289
Batch fecundity	39304.0130020	646215.835451
Spawners, Day 0	0.08945686901	0.00058393344
Spawners ave (Day 1 + Day2)	0.10377367610	0.00053794519
Sex Ratio	0.57380069678	0.00144356584
Daily specific fecundity	18.0713434364	
Number of Sets	17	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.94715706	0.30897171	-0.1482456
Batch Fecundity (F)			0.42785244	-0.0991688
Fraction Spawning (S)				-0.2723886
Sex Ratio (R)				

[a] Area of Region 1 is 27,462 km^2, Region 2 DEPM area is 244,311 km^2, and the DEPM area is 271,773 km^2

Table 6. Estimated 2010 adult parameters and correlations for the total Region 2 survey area (449,630 km^2) and the whole CCE survey area (477,092 km^2) outputted from the EPM program (Appendix II Chen et al. 2003). For Region 1 results, see Table 5.

Region 2 for the whole CCE survey area

Statistic Results:

	Average	Variance
Whole Body Weight	130.826314820	9.25619210526
Gonad Fee Weight	122.499338129	8.29738809062
Batch fecundity	39329.8008326	2252848.71184
Spawners, Day 0	0.09712230216	0.00074719700
Spawners ave (Day 1+Day2)	0.10035854301	0.0007253658
Sex Ratio	0.61937724528	0.00077507104
Daily specific fecundity	18.6868557368	
Number of Sets	15	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.96032453	0.45189526	0.13557540
Batch Fecundity (F)			0.49376781	0.02907519
Fraction Spawning (S)				0.04948230
Sex Ratio (R)				

Whole CCE survey area

Statistic Results:

	Average	Variance
Whole Body Weight	131.314459645	6.40339328993
Gonad Fee Weight	123.063254438	5.81733158951
Batch fecundity	39741.2135211	1984837.76496
Spawners, Day 0	0.10059171598	0.00061854928
Spawners ave (Day1+Day2)	0.11240885839	0.00053561534
Sex Ratio	0.58562183920	0.00134888275
Daily specific fecundity	19.9226164921	
Number of Sets	18	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.93493413	0.47148944	0.09631907
Batch Fecundity (F)			0.53290076	0.05579602
Fraction Spawning (S)				-0.1349569
Sex Ratio (R)				

Table 7 The spawning biomass and related parameters: daily egg production/0.05m^2 (P_0),daily mortality rate (z), DEPM survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2005 and 2007-2010

Calendar year	Season	Region	[1]P_0/0.05m^2 (cv)	Z (CV)	[2]RSF/W based on S_1	[3]RSF/W based on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
1986 (Aug)	1986	[6]S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987 (July)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5
2010	2009	1	1.70(0.36)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.50)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.40)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9

1: P_0 for the whole is the weighted average with area as the weight.
2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008)
3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2,
4. Region 1, since 1997, is the area where the eggs/min from CUFES $\geq$1 and prior to 1997, is the area where the eggs/0.05m^2 >0 from CalVET tows
5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters
6. Within southern and northern area,, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs)

Table 8. Temperature range (3m depth) and presence (+) of Pacific sardine eggs collected in CUFES samples and adults taken in trawls during the spring 2006, 2008, and 2010 surveys off the west coast of the United States.

Survey Information	**April 2006**	**April 2008**	**April 2010**
Washington – Oregon: 48.5° – 42°N			
Sea Temperature Range	9.1-11.8°C	8.2-10.1 °C	9.5-11.4°C
Mean °C of sardine positive trawls	na	na	na
Number positive trawls (total)	0 (9)	0 (25)	0 (12)
Number of sardine sampled	-	-	-
Mean body weight (g)	-	-	-
Eggs, Region 1	+	-	-
Eggs, Region 2	+	-	-
Northern California: 42°N – CalCOFI line 60			
Sea Temperature Range	10.8-12.2°C	7.8-11.6°C *	9.6-13.2°C
Mean °C of sardine positive trawls	11.4°C	11.5°C	13.2°C
Number positive trawls (total)	3 (4)	1 (15)	1 (17)
Number of sardine sampled	101	1	50
Mean body weight (g)	91g	148g	152g
Eggs, Region 1	+	-	-
Eggs, Region 2	+	+	+
standard DEPM: CalCOFI lines 60 – 95 (San Francisco – San Diego)			
Sea Temperature Range	13.3-16.6°C	11.2-15.5°C	12.1-15.9°C
Mean °C of sardine positive trawls	14.4°C	12.4°C	13.6°C
Number positive trawls (total)	7 (22)	12 (31)	18 (68)
Number of sardine sampled	194	353	635
Mean body weight (g)	67g	105g	127g
Eggs, Region 1 (area, km^2)	+ (98034)	+ (53514)	+ (27462)
Eggs, Region 2	+	+	+
Whole DEPM area P_0	1.96	0.43	0.36

* a single negative offshore trawl at 38.4°N recorded 13.2°C

Table 9. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007	2008	2009	2010
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27	04/17-05/06	04/12-04/27
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4	12.93	13.62
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574
Average mature female weight (grams):												
with ovary	**W_f**	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51
without ovary	**W_{of}**	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34
Average batch fecundity[a] (mature females, oocytes estimated)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313
N active mature females		327	77	9	23	290	148	72	187	177	463	310
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186	0.1098	0.1038
Spawning fraction of active females[c]	**S_a**	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048
Daily specific fecundity	**RSF W**	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07

[a] 1994-2001 estimates were calculated using $F_b = -10858 + 439.53\ W_{of}$ (Macewicz et al. 1996), 2004 used $F_b = 356.46 W_{of}$. (Lo and Macewicz 2004), 2005 used $F_b = -6085 + 376.28\ W_{of}$ (Lo and Macewicz 2006), 2006 used $F_b = -396 + 293.39\ W_{of}$ (Lo et al. 2007a); 2007 used $F_b = 279.23 W_{of}$ (Lo et al. 2007b), 2008 used $F_b = 305.14 W_{of}$ (Lo et al. 2008), 2009 used $F_b = -4598 + 326.78 W_{of} + e$ (Lo et al. 2009).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season).. S_1 was used for years prior to 2009 and S_{12} was used staring 2009.

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

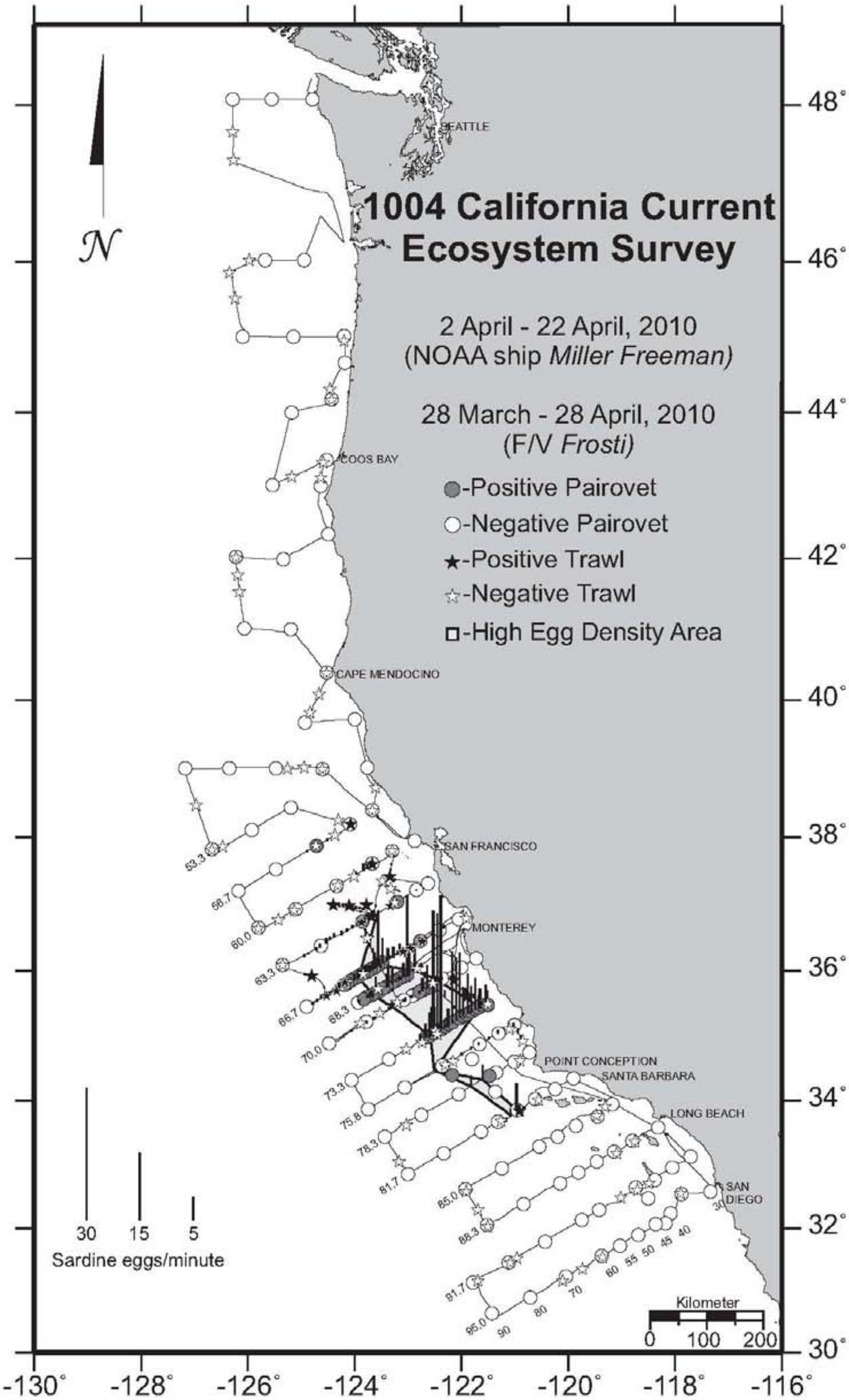

Figure 1. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2010 survey. Shaded area is Region 1, the high egg-density area, and the rest of survey area is Region 2.

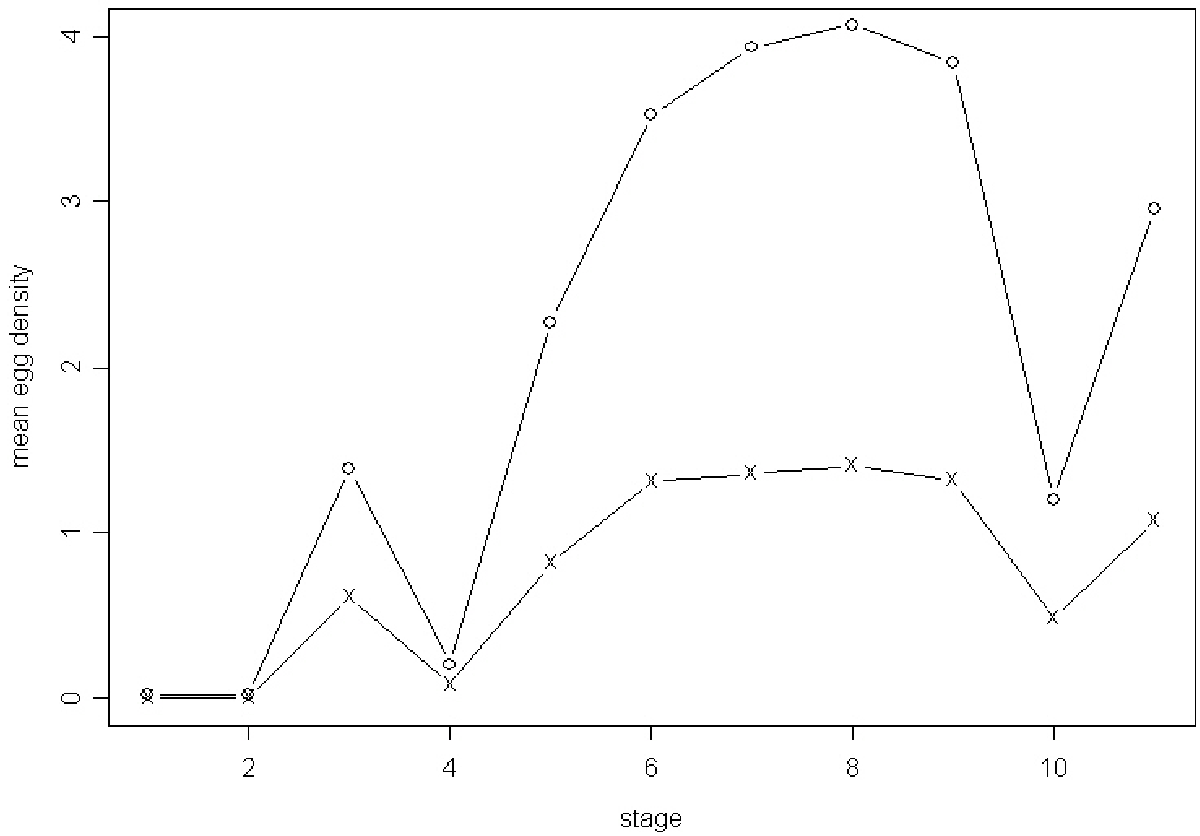

Figure 2. Mean sardine egg density (eggs per 0.05 m^2) for each developmental stage within each area for April 2010. Symbols: o = Region 1 and x = DEPM survey area (CalCOFI line 95 to 60).

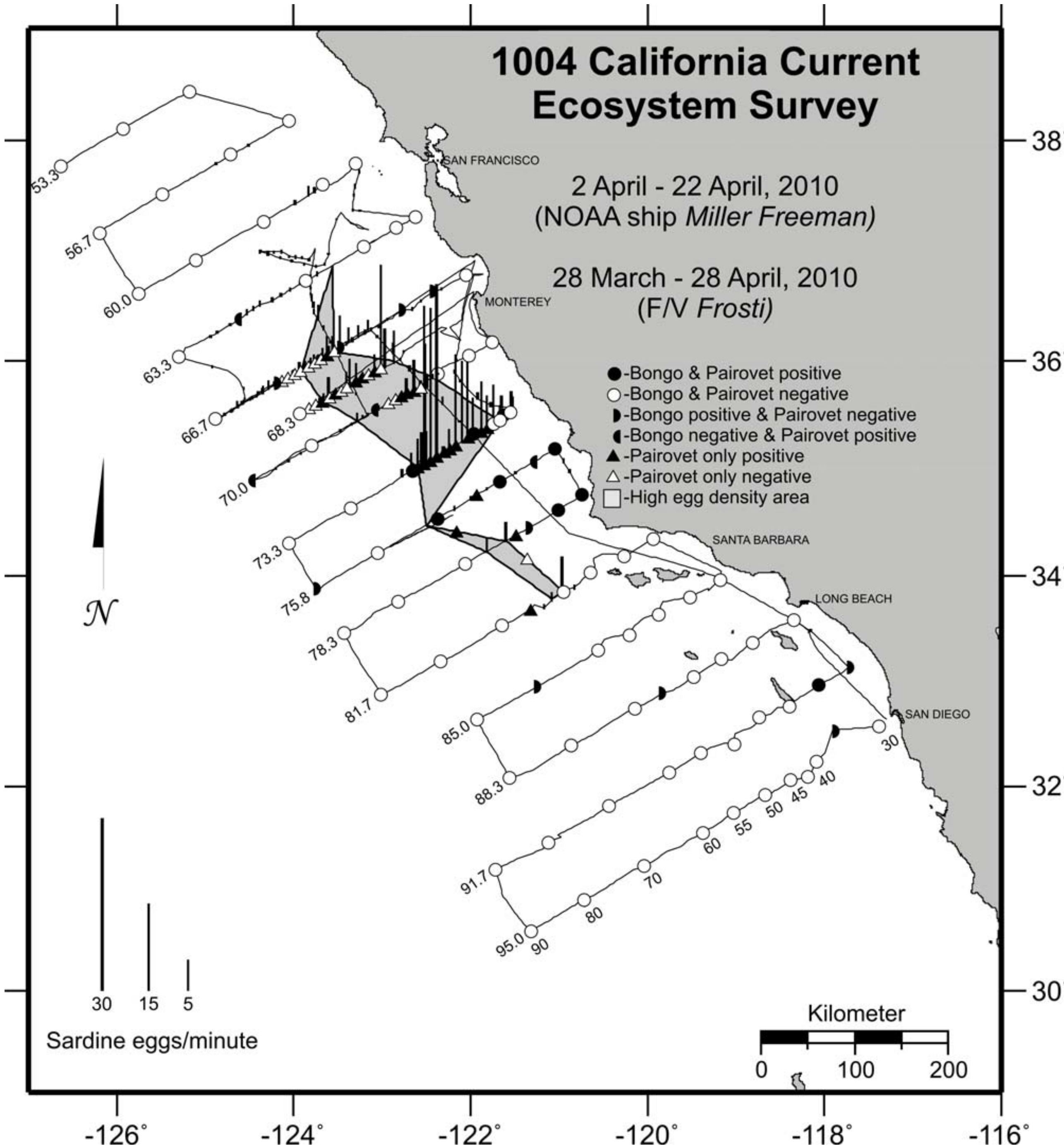

Figure 3. Location of sardine yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) during the 2010 survey. Solid symbols are positive and open symbols are zero catch. Few yolk-sac larvae were caught north of CalCOFI line 60.0. The shaded area is Region 1: the high egg-density area. Region 2 in the standard DEPM area includes the rest of the survey area shown between CalCOFI line 95.0 and 60.0.

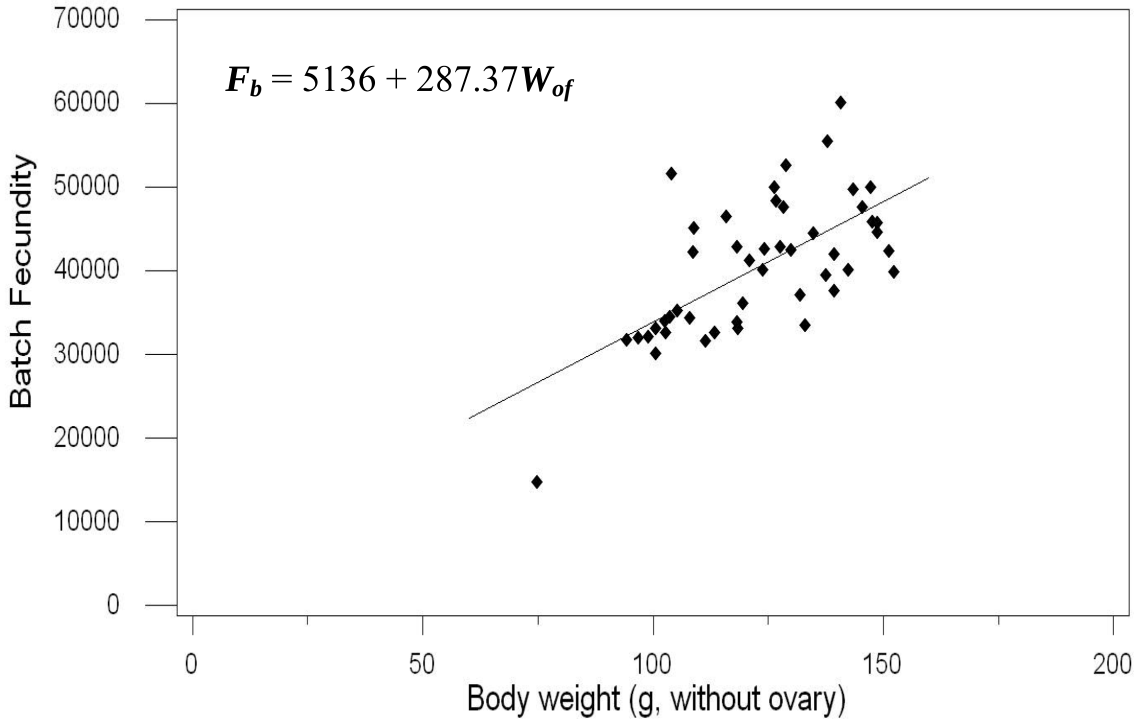

Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 47 females taken during April 2010. The batch was estimated from numbers of hydrated or migratory-nucleus-stage oocytes.

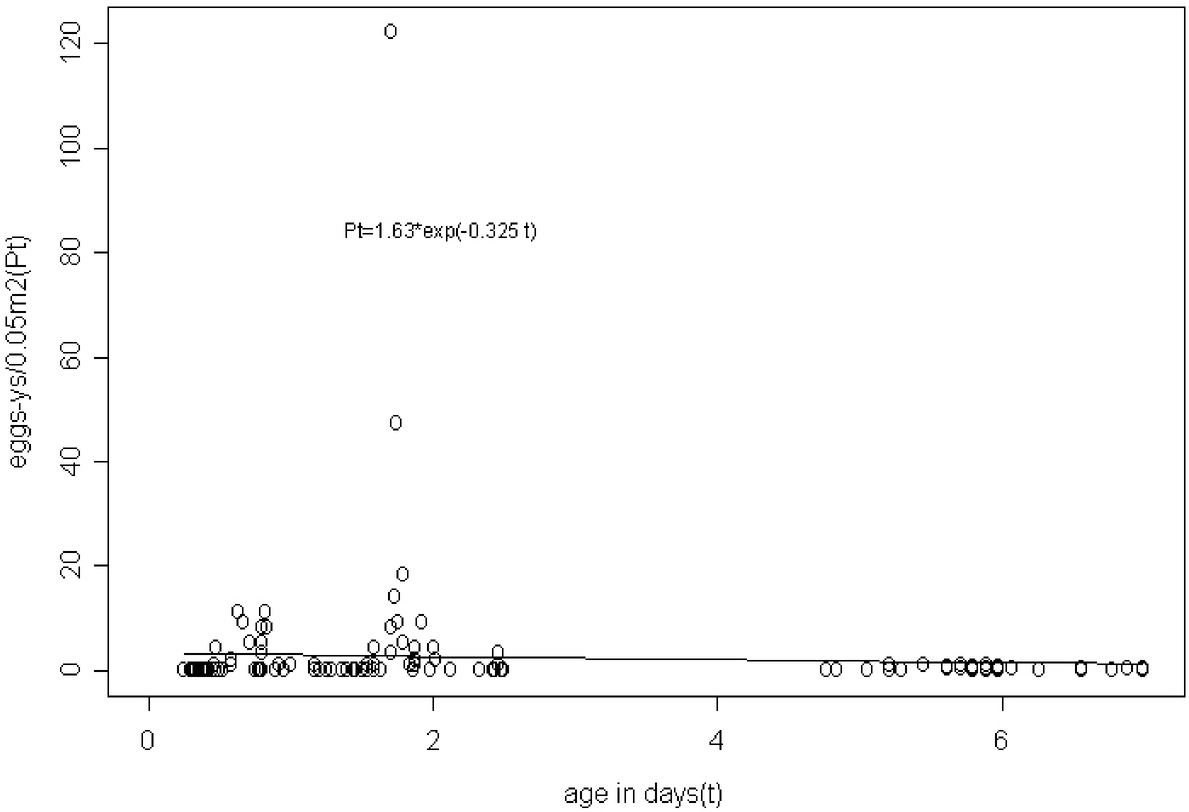

Figure 5. Embryonic mortality curve of Pacific sardines. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April 2010, aboard *Miller Freeman* and *Frosti*. The number, 1.63, is the estimate of daily egg production at age 0 (P_0) before correction for bias.

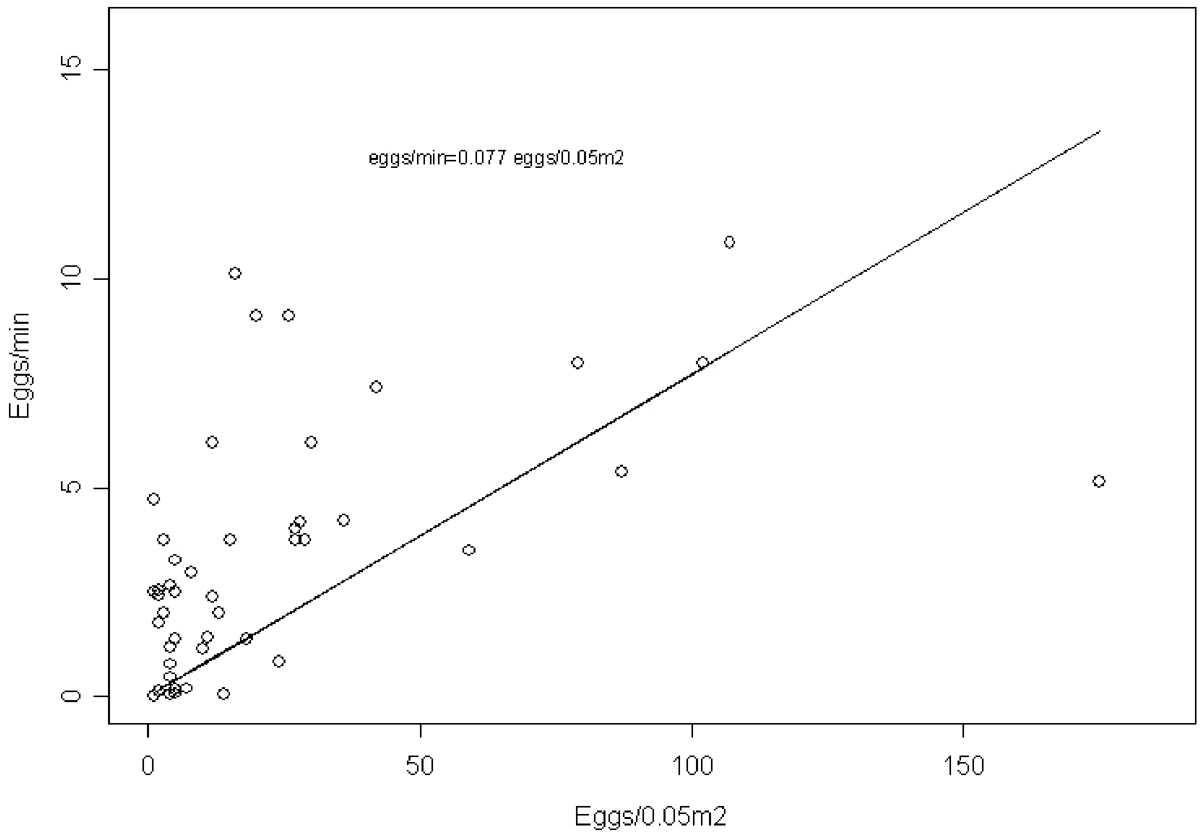

Figure 6. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April 2010 from *Miller Freeman* collections.

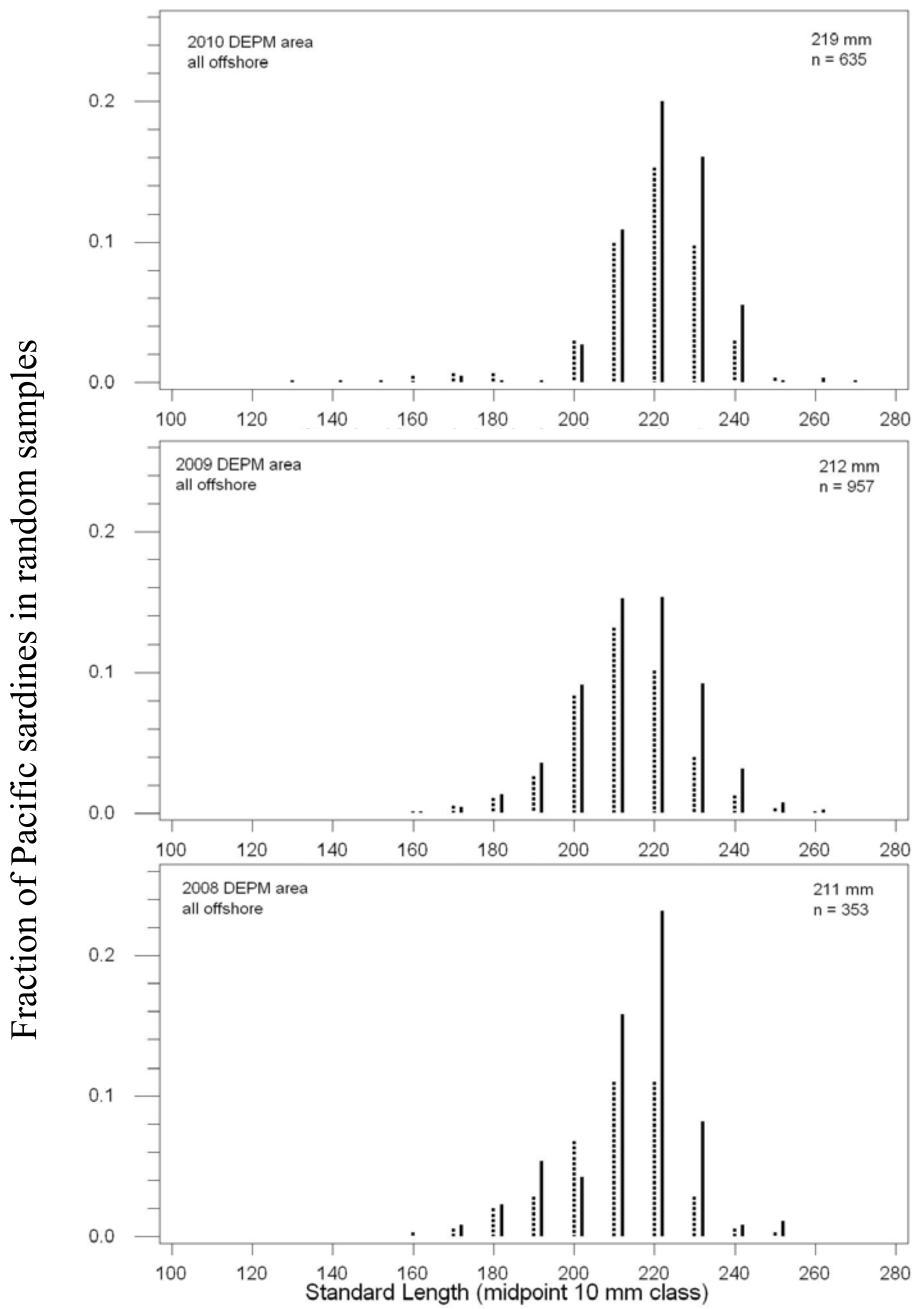

Figure 7. Length distribution and mean length of Pacific sardines caught in the 2010, 2009 and 2008 DEPM survey areas. Males indicated by dotted bars and females by solid bar.

RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (http://swfsc.noaa.gov). Copies are also available form the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (http://www.ntis.gov). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-453 U.S. Pacific marine mammal stock assessments: 2009
J.V. CARRETTA, K.A. FORNEY, M.S. LOWRY, J. BARLOW, J. BAKER, D. JOHNSTON, B. HANSON, R.L. BROWNELL, JR., J. ROBBINS, D.K. MATTILA, K. RALLS, M.M. MUTO, D. LYNCH, and L. CARSWELL
(January 2010)

454 Operation of dual-frequency identification sonar (DIDSON) to monitor adult steelhead *(Oncorhynchus mykiss)* in the central California coast.
K. PIPAL, M. JESSOP, G. HOLT, and P. ADAMS
(February 2010)

455 Evaluation of a Marine Mammal Excluder Device (MMED) for a Nordic 264 Midwater Rope Trawl.
R.C. DOTSON, D.A. GRIFFITH, D.L. KING, and R.L. EMMETT
(February 2010)

456 Cetacean abundance in the California Current estimated from a 2008 ship-based line-transect survey.
J. BARLOW
(February 2010)

457 Variation and Predictors of Vessel-Response Behavior in a Tropical Dolphin Community.
F.I. ARCHER, S.L. MESNICK, A.C. ALLEN
(March 2010)

458 Evidence of genetic differentiation for Hawai'i insular false killer whales *(Pseudorca crassidens)*.
S.J. CHIVERS, R.W. BAIRD, K.M. MARTIEN, B.L. TAYLOR, E. ARCHER, A.M. GORGONE, B.L. HANCOCK, N.M. HEDRICK, D. MATILLA, D.J. McSWEENEY, E.M. OLESON, C.L. PALMER, V. PEASE, K.M. ROBERTSON, J. ROBBINS, J.C. SALINAS G.S. SCHORR, M. SCHULTZ, J.L. THEILEKING, and D.L. WEBSTER
(June 2010)

459 Assessing trends in abundance for vaquita using acoustic monitoring: within refuge plan and outside refuge research needs.
L. ROJAS-BRACHO, A. JARAMILLO-LEGORETTA, G. CARDENAS, E. NIETO, P. LADRON DE GUEVARA, B.L. TAYLOR, J. BARLOW, T. GERRODETTE, A. HENRY, N. TREGENZA, R. SWIFT, and T. AKAMATSU
(July 2010)

460 Estimates of sustainable yield for 50 data-poor stocks in the Pacific Coast groundfish fishery management plan.
E.J. DICK and A.D. MacCALL
(June 2010)

461 Documentation of the California catch reconstruction project.
S. RALSTON, D.E. PEARSON, J.C. FIELD, and M. KEY
(July 2010)

462 Serious injury determinations for cetaceans caught in Hawaii longline fisheries during 1994-2008. U.S. Dep. Commer., NOAA Tech. Memo. NOAA Tech. Memo. NMFS-SWFSC-462.
(September 2010)